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FLOW OF VISCOUS GAS IN THE REGION OF A SLOT WITH STRONG SUCTION

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16. Abstract
The flow of a perfect viscous gas was studied in the region of a slot with strong suction. The distribution fields of velocities and temperatures are computed for the case of thermally insulated and heat-conducting surfaces. The dependence of the flow characteristics on the suction gas discharge is obtained for a single slot with strong suction.

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FLOW OF VISCOUS GAS IN THE REGION OF A SLOT WITH STRONG SUCTION

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On the basis of the continuity equation and simple geometric considerations, G. Lachmann [1] developed an approximate method of calculation of the characteristics of a laminar boundary layer in an uncompressed fluid near a slot with suction. With the aid of the law of conservation of momentum, W. Colemann [2] succeeded in more strictly grounding the method mentioned. Both studies were explained in monograph [3]. This study is devoted to a theoretical investigation of the flow of a perfect viscous gas in the region of a slot with strong suction. A solution was obtained for an incompressible fluid, as a separate case. /538*

The differential equations for the case of nonstationary flow of a viscous gas, in the absence of general forces, take the form [4]:

$$
\left.
\begin{aligned}
\rho\frac{du}{dt} &= -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left[\mu\left(2\frac{\partial u}{\partial x} - \frac{2}{3}\operatorname{div}\vec{w}\right)\right] + \\
&+ \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right], \\
\rho\frac{dv}{dt} &= -\frac{\partial p}{\partial y} + \frac{\partial}{\partial y}\left[\mu\left(2\frac{\partial v}{\partial y} - \frac{2}{3}\operatorname{div}\vec{w}\right)\right] + \\
&+ \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right] + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right], \\
\rho\frac{dw}{dt} &= -\frac{\partial p}{\partial z} + \frac{\partial}{\partial z}\left[\mu\left(2\frac{\partial w}{\partial z} - \frac{2}{3}\operatorname{div}\vec{w}\right)\right] + \\
&+ \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right] + \frac{\partial u}{dy}\left[\mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right],
\end{aligned}
\right\} \qquad (1)
$$

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*Numbers in the margin indicate pagination in the foreign text.

where $\vec{w} = \vec{i}u + \vec{j}v + \vec{k}w$ is the velocity vector; u, v, w are the projections of the velocity vector on the axes of a rectangular coordinate system; p is the pressure; ρ is the density of the gas; μ is the dynamic coefficient of viscosity of the gas.

These equations must be supplemented by the equation of continuity

$$\frac{\partial \rho}{\partial t} + \operatorname{div}(\rho \vec{w}) = 0 \qquad (2)$$

and the energy equation

$$\rho C p \frac{dT}{dt} = \frac{dp}{dt} + \left[\frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right)\right] + \mu \Phi, \qquad (3)$$

where /539

$$\Phi = 2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 - \frac{2}{3}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{dy} + \frac{\partial w}{\partial z}\right)^2 -$$

is a dissipative function; Cp is the specific heat of the gas at constant pressure, per unit mass; λ is the coefficient of thermal conductivity.

Besides, in considering the gas to be perfect, we will have

$$p = \rho R T, \qquad (4)$$

where R is the gas constant; T is the absolute temperature.

Finally, there is the correlation required for a closed system of equations to give the empirical relation

$$\mu = \mu(T). \qquad (5)$$

The boundary conditions were implemented for the region $x_0 \leq x \leq x_0 + S$, where x_0 is the coordinate of the leading side of the slot; S is the width of the slot.

Two cases are considered in the articles:

a) Heat insulation of the surface

$$\left.\begin{array}{ll}\text{with} & y=0\ u=0;\ v=-v_0;\ \dfrac{\partial T}{\partial y}=0;\\ \text{with} & y=\infty\ u=U_\infty;\ \dfrac{\partial u}{\partial y}=0;\ T=T_\infty.\end{array}\right\} \tag{6}$$

In this case, convective heat transfer is disregarded, on condition of suction of the gas through the slots;

b) Heat conduction of the surface /540

$$\left.\begin{array}{ll}\text{with} & y=0\ u=0;\ v=-v_0;\ T=T_{\text{ст}};\\ \text{with} & y=\infty\ u=U_\infty;\ \dfrac{\partial u}{\partial y}=0;\ T=T_\infty.\end{array}\right\} \tag{7}$$

These assumptions are made in the subsequent calculations: the gas flow is stationary and smooth; the dynamic coefficient of viscosity of the gas is reduced in proportion to density; no effect of the distant gas flow develops in the section $x = x_0 + S$; the Reynolds number, based on the width of the slot and the velocity of the incoming flow, an order of magnitude higher than the dimensionless width of the slot, relative to the loss of impulse on the leading edge of the slot; the suction in the slot is stronger, so that $\frac{Q_i\delta^{xx}_{i,2}}{S_i\nu} \gg 0{,}5$, where Q_i is the bulk flow rate of the gas sucked through the i=th slot; ν is the kinematic coefficient of viscosity of the gas; $\delta^{xx}{}_{i,2}$ is the loss of impulse in the area of the trailing edge of the i-th slot.

After simplification of system of equations (1)-(5), on the basis of the assumptions indicated and calculating boundary conditions (6)-(7), the velocity and temperature distribution fields across the boundary layer were calculated, as a function of the Mach number and the temperature ratio T_{ct}/T_∞. As an example, the results of calculations for M = 2 and temperature ratio T_{ct}/T_∞ = 1.0-1.8, in the section near the trailing edge of the slot on a heat conducting surface, is plotted in Fig. 1, in the form of continuous curves. For comparison, similar data for M = 3 and temperature ratio T_{ct}/T_∞ = 1.6, is shown in the same graph by a dashed line.

The corresponding data for a heat insulated surface and M = 1 and M = 2 also are plotted in Fig. 1, by means of dot-dashed lines.

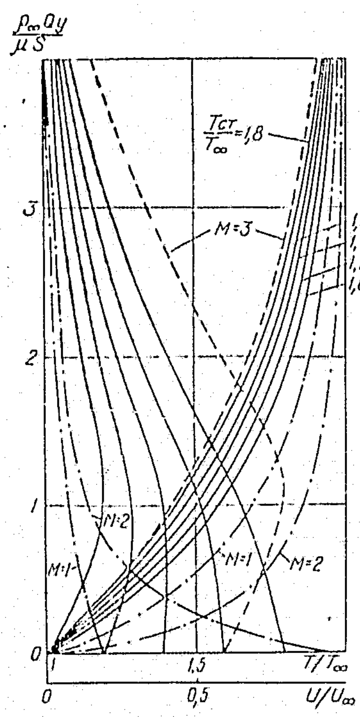

Fig. 1.

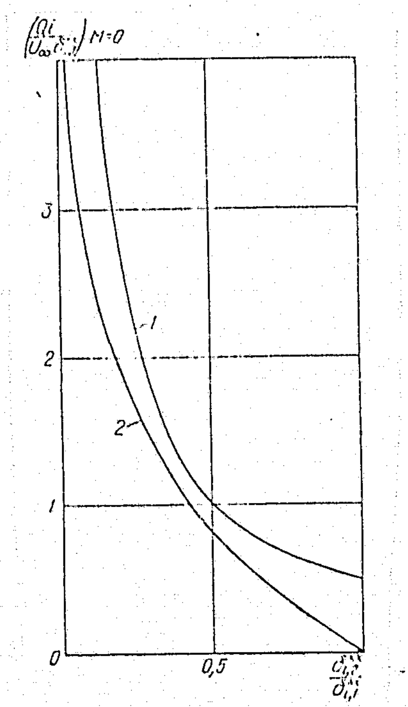

Fig. 2.

Besides, the loss of gas suction through the i-th slot Q_i vs. the loss of impulse on the trailing and leading edges of the slot $\delta^{xx}{}_{i,2}/\delta^{xx}{}_{i,1}$ was obtained by computer. This relation for an incompressible fluid is presented in Fig. 2 (curve 1) in dimensionless form. For comparison, the relation obtained by Lachmann [1] (curve 2) is presented in the same graph. From analysis of these results, it should be noted that, in the interval of values of $\delta^{xx}{}_{i,2}/\delta^{xx}{}_{i,1}$ = 0.3-0.6, curves 1 and 2 differ by 10-25%. In different intervals of change of $\delta^{xx}_{i,2}/\delta^{xx}_{i,1}$, the divergence between curves 1 and 2 is more evident. It is evident that curve 1 is entirely satisfactorily confirmed by actual experiments.

For a compressed gas, a relationship is obtained in the form

$$\frac{Q_i}{U_\infty \delta^{xx}_{i,1}} = 2k\left(M, \frac{T_{\text{ст}}}{T_\infty}\right)\left(\frac{Q_i}{U_\infty \delta^{xx}_{i,1}}\right)_{M=0}. \qquad (8)$$

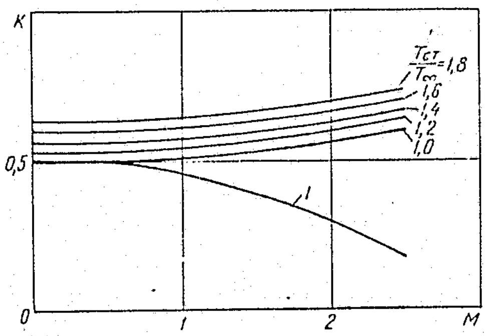

Fig. 3.

Coefficient K vs. Mach number and the ratio of the surface and incoming flow temperatures T_{ct}/T_∞ is presented in Fig. 3, for a heat insulated (curve 1) and a heat conducting (the other curves) surface.

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